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# The Metallurgist.

*Supplement to* The Engineer, *April, 1933.*

## Chills.

Every foundryman, whether he deals with iron, steel, or non-ferrous metals, is well aware of the important part played by the use of chills in his work. There is, of course, the whole class of castings which are definitely made in chill moulds, or, as they are frequently called, metal "dies." These, however, constitute a class by themselves, involving a special technique, and they have to be considered separately. At the moment we are concerned with the use of partial chills introduced in the production of sand castings for various purposes. In the non-ferrous industries their use is mainly that of providing for more rapid local cooling in certain parts of the mould, and for that purpose these chills, which are, of course, merely pieces of metal, generally iron or steel, are inserted at appropriate points in such a way that one face of the metal chill forms part of the mould wall itself, and thus comes into direct contact with the molten metal or alloy which fills the mould.

There can be no doubt that the proper use of chills plays an important part in the production of sound and strong castings. For example, where a relatively heavy section has to be cast in juxtaposition with lighter portions of a casting, the use of chills for accelerating the cooling of the larger body of metal in the thicker portions plays an important part in equalising the rate of solidification throughout the whole body. It particularly prevents contraction becoming more or less localised in those portions of a casting which are the last to solidify. If no special means of local cooling are employed, the metal at these places remains liquid while the thinner portions of the casting are undergoing solidification. In consequence the solidification shrinkage of the thinner portions is made up by drawing upon the liquid still present in the thicker portions and contraction or "drawing" results. If by the use of chills the cooling of the thicker portions is accelerated sufficiently, there is no longer any danger of liquid from these parts feeding the thinner portions, and so far as the soundness of the thicker portions is concerned, a more satisfactory result is obtained. It is, however, sometimes forgotten by the foundryman and the moulder that the prevention of shrinkage or drawing in the thicker portions may be achieved at the expense of unsoundness in the thinner portions, and more particularly at the points where the thinner sections adjoin or merge into the thicker ones. By accelerating the cooling of the larger masses of metal in the mould the real contraction shrinkage of the thinner portions is not prevented, and unless the gating and feeding of the casting is so adjusted that the thinner portions as well as the heavier sections can draw upon liquid metal from gates or risers, unsoundness at one point or another is certain to occur, even where chills are skilfully used.

Chills are, of course, also used for other purposes. In some cases a local chilling effect is desired, in order to secure, in a given portion of the casting, superior or satisfactory mechanical properties which are not readily obtained when the metal in question is cooled at the normal rate of a sand casting. This device is sometimes employed, more or less surreptitiously, for the purpose of securing specified properties in a casting or part of a casting which is to be used as a test piece, but this is a practice which in many instances so far exceeds the limitations of honest practice that it can only be left to the keenness of the inspector to detect and prevent it in all cases where it involves a circumvention of a specification. Apart from such highly undesirable use of chills, however, there are many points about their employment which do not always receive full consideration. For example, the actual heat capacity of the chills employed has to be considered. A small piece of iron or steel embedded in the wall of a mould which holds many hundreds or even thousands of pounds of molten alloy will obviously have very little effect. Usually it is supposed that the effect of a chill will be approximately proportional to its weight. This idea is based on the assumption that the chill absorbs heat until it is raised to a certain temperature near to that of the solidifying metal, and thereafter produces very little effect. Up to a certain point this is correct, but it must be borne in mind that the thermal conductivity of iron and steel is not very high, and that where very large chills are used, the flow of heat into the more distant portions of the piece of metal occupies an appreciable time, which may be as great or even greater than the time occupied by the freezing of the metal in contact with the chill. Another important factor, besides the mass and thermal conductivity of the chill itself, lies in the nature and thickness of any dressing which may be applied to the mould face and therefore to the face of the chill itself. Certain dressings go far to neutralise the effect of the chill by interposing considerable resistance to the transfer of heat from the molten metal. In other cases the liquid metal itself becomes coated with an oxide skin which acts in the same manner. The method of pouring, which will to some extent determine the amount of oxidation which the metal receives in the process, may therefore affect the influence of chills.

In the steel industry use is frequently made of another type of chill which is inserted, not in the wall of the mould, but in the mould space proper. Chills used in this way are intended to become amalgamated with the molten steel entering the mould by complete or at least partial fusion. Their effect, while to some extent due to the absorption of heat

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from the surrounding molten steel and the consequent acceleration of freezing, is due in part also to the fact that, being already solid, they diminish the volume of metal in which solidification contraction occurs. From both these points of view they are, of course, decidedly effective, but there is none the less a serious objection to their use. This arises from the fact that frequently they do not amalgamate with the molten steel, even by partial fusion, with the result that discontinuities are left in the casting, and these weaken it in a manner which unavoidably leads to failure. Instances of this kind, even in very large castings, are well known. The danger can be to some extent avoided by using considerably superheated steel for pouring the casting, but this brings with it other serious disadvantages, among which "burning on" of the mould sand may be mentioned. Further, even where adequate amalgamation takes place between these internal chills and the molten steel, complete fusion rarely occurs; in fact, if it does occur, one of the principal purposes of the chill is missed. It follows, therefore, that a casting made with such chills is liable to be markedly inhomogeneous, because it will contain inclusions of steel of different texture and usually of different composition from that of the rest of the casting. In recognition of these facts it has come to be the practice to insist that internal chills used in steel castings shall not be larger than the horseshoe nail which is frequently used for this purpose. Even with this limitation, however, the risks are not entirely avoided, especially where a large number of such nails are introduced into the mould close together. The adoption of these methods is, we think, to be regarded as a serious confession of weakness in regard to proper gating and feeding of the castings. If steel castings are to be satisfactorily used, and to compete successfully with fabricated articles made from rolled material, avoidance of a practice which is admittedly liable to serious risks will have to be carefully considered by the makers of castings.

## Small Impurities.

METALLURGISTS are becoming increasingly aware of the important part which small proportions of another element—metal or metalloid—may play in determining the properties of an otherwise "pure" metal or even of an alloy. This realisation is due in part to the fact that the increasing perfection of metallurgical technique, especially in regard to research, has made it possible to examine metals of higher purity than those formerly available. Even now, however, we are far from having obtained some of our most important metals in a state of such purity that we can safely ignore the effect of the other substances still present, even although in some cases no one other body occurs in a greater proportion than 0·001 per cent., that is to say, one part per hundred thousand. Possibly the most striking example of this kind is the metal iron itself. Jensen, as the result of his own work, has tentatively suggested that the allotropic transformations which are so familiar a feature in the behaviour of every variety of iron that has yet been produced may be, in reality, due to the presence of impurities. It has not yet been possible either to verify or to refute this suggestion because, in spite of the large amount of skill and ingenuity which has been devoted to the subject, the production of iron free from impurities, both gaseous and solid, to one part in a million, has not yet been realised. In some few instances metals have been prepared with this degree of purity, gold being a favourable example, while probably the variety of zinc known as "spectroscopically pure" is of the same order of purity. In the latter case remarkable properties, especially in regard to solubility in acids, have been observed. In quite another direction we have recently seen, from a paper presented to the Institute of Metals at its last meeting, the important effect which the presence of not much more than 0·05 per cent. of tellurium produces in lead. Many of those who listened to that paper were much impressed by the apparently inexplicable potency of so small an addition. There are, however, other cases in which additions, while still relatively small in amount, produce still more marked effects. For instance, the addition of less than 2 per cent. of beryllium to copper can be made to change the tensile strength of that metal from 12 or 14 tons to something of the order of 80 or 90 tons per square inch, while, of course, the effect of a few one-tenths of a per cent. of carbon upon the tensile strength of steel is so familiar that its truly remarkable nature is apt to be overlooked.

It is, however, of some interest to inquire as far as we can into the mechanism of these effects. Broadly they must depend upon the form in which the impurity or addition is present in the metal. In some cases a potent effect is produced because the impurity, or a weak and brittle compound which it may form, becomes segregated into the crystal boundaries. The most familiar example of this kind is the effect of bismuth upon gold. In other cases the added element, such as carbon in steel, is present not only in the form of a compound with the basis metal (in the case of steel this is, of course, the well-known body $Fe_3C$), but this compound itself occurs as an eutectic or eutectoid with the basis metal. Thus steel containing only 0·9 per cent. of carbon consists entirely of the pearlite eutectoid, which, naturally, has properties very widely different from those of pure iron, so that even when, with lower carbon content, only a small proportion of the material consists of the eutectoid its presence is still sufficient to affect the properties to a very marked degree. It is probable that in the case of beryllium also its potent effect is due in part to the fact that it exists, particularly after precipitation from solid solution during the ageing process, as a compound with copper which constitutes a considerable proportion of the mass. The case of tellurium in lead is, however, typical of another kind of distribution of an impurity or added element. Here, we believe, we have to deal with a true solid solution which probably never undergoes decomposition, and therefore, at first sight, the relatively large effect of a small percentage addition is more difficult to understand. We can, however, form a better conception of how these relatively minute additions produce their effect if we think of the matter in terms of atoms rather than of percentages by weight. Since the atomic weights of tellurium and lead are respectively 127·5 and 207·2, the atomic percentage, corresponding to a weight percentage of 0·06, is 0·1. This means that there is one atom of tellurium for every thousand atoms of lead. If now we think of the matter in terms of the lattice structure of the metal we can still better understand the effect which these tellurium atoms produce. In a close-packed face-centred lattice like that of lead every atom is in direct contact or, if we prefer it, in the closest possible juxtaposition to twelve other atoms.

The result is that, in a solid solution containing tellurium, twelve atoms of lead are in immediate contact with each tellurium atom. These twelve in turn are in direct contact with forty-two others, so that fifty atoms are not more than two atomic spaces away from the tellurium atom, and we may well expect that the influence of that stranger atom upon the surrounding lattice may extend a good deal further than two atomic distances. Looked at in another way, we may suppose, for the sake of simplification, that the atoms of the basis metal are arranged not in the close-packed face-centred lattice, but in the more open cubic lattice, in which there is an atom at every corner of the cube. If one of these is replaced by a stranger, twenty-six adjacent atoms lie within a distance of less than two atomic spaces from the stranger, while, with a proportion of one stranger atom to a thousand atoms of the basis metal, we should find that for even distribution no individual atom of the basis metal is more than five atomic spacings removed from the nearest stranger atom. Particularly in a very soft metal like lead, whose atoms are known to be easily moved relatively to each other, we should anticipate that the influence of a stranger atom of widely different nature would extend well beyond five atomic spacings and consequently, looked at in this light, the effect of the relatively few tellurium atoms which are present in a lead alloy containing 0·06 per cent. of that element by weight is more readily understood.

With this conception, however, we are bound to realise that impurities which we frequently regard as negligible or unavoidable may yet play a far more important part in determining the properties of our materials than we might suppose. Metallurgists have sometimes been inclined to smile at a specification which demands that not more than 0·001 per cent. of a given impurity (such as bismuth in copper) shall be present. While we still think that so extreme a specification requires very full justification, we cannot avoid the conclusion that the harmlessness of even very minute contaminations cannot be taken for granted.

## The Constitution of the Nickel-Zinc Alloys.

THE determination of the constitution of a series of alloys, one component of which has a boiling point much lower than the melting point of the other, is generally a matter of some difficulty. This arises partly because it is not easy to make up the alloys, and partly because it is frequently impossible to take thermal curves at normal pressures of alloys rich in the high melting point constituent, while, if they are taken under high pressures, the effect of this on the composition and range of the phases should, strictly speaking, be taken into account. It happens, fortunately, that in the nickel-zinc system the fact that the boiling point of zinc is as much as 500 deg. Cent. below the melting point of nickel does not introduce much uncertainty into the diagram, as, with pressures as low as two atmospheres, Tamaru* has shown that it is possible to take thermal curves of alloys containing as much as 70 per cent. of nickel. A pressure of two atmospheres is unlikely to have an appreciable effect on the phase distribution, and the form of the diagram is such that it is probably fairly safe to extrapolate the liquidus and solidus backwards from 70 per cent. to 100 per cent. nickel. It must be emphasised, however, that it is but a fortunate chance that such a treatment is possible in this series of alloys, and while it is unlikely to introduce any serious errors, it can hardly be regarded as thoroughly satisfactory.

The diagram obtained by Tamaru is given in Fig. 1 and shows that the system is a fairly complicated one. In determining it, use was made of thermal analysis (both differential and direct or, as the author calls it, "total thermal analysis"), electrical, resistivity measurements, dilatometric measurements, and magnetic analysis. It is a little difficult to estimate the value of the results in some respects, because the description given of methods, precautions, &c., is very meagre, and the legends on some of the diagrams

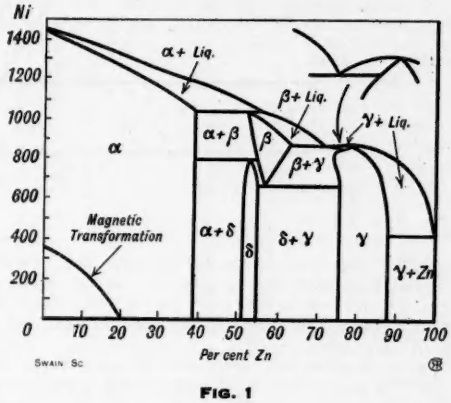



FIG. 1

are very carelessly given and are apt to be misleading. It may be said, however, that it is evident that a great deal of work has been done, and that the general lines of the diagram can probably be taken as accurate.

The thermal analysis appears to have been restricted to cooling curves, except that certain solidus determinations are marked on the diagram as having been obtained from "total thermal analysis (heating)." There are only two lines which have been determined by direct cooling curves as well as by other methods. Of these one is the $\alpha+\beta=\delta$ transformation. Here the results of the cooling curves agree within 3 deg. Cent. with those obtained by other methods. The other case is the $\beta=\gamma+\delta$ transformation, where there is a difference of over 30 deg. Cent. between the results obtained on cooling curves and those given by other methods. In the case of electrical resistivity measurements it appears that the mean values of data from heating and cooling are given, but from some of the curves plotted it can be deduced that there may be a difference as great as 50 deg. Cent. between the results obtained on heating and on cooling, and that the electrical resistivity cooling curves agree with the thermal cooling curves. The mean values obtained by dilatometric measurements agree very well with the resistivity ones, but the heating and cooling curves are in somewhat better agreement with each other in the former case.

The microscopic study of the structure of the alloys

* K. Tamaru. On the "Equilibrium Diagram of the Nickel-zinc System," Sc. Rep., Tôhoku Imperial University, 1932, 21, 344.

is the least satisfactory part of the work. The limits of the δ phase appear to have been micrographically determined on alloys that were given no heat treatment. The boundaries between α and α+δ and that between γ and γ+δ seem to have been determined from alloys slowly cooled to room temperature, while an X-ray examination of the whole series were carried out. The magnetic transformation in nickel is rapidly depressed by the addition of zinc; it occurs at 0 deg. Cent. when 20 per cent. of zinc is present.

The X-ray analysis shows that the structure of the α and γ phases is cubic, while β and δ are hexagonal.

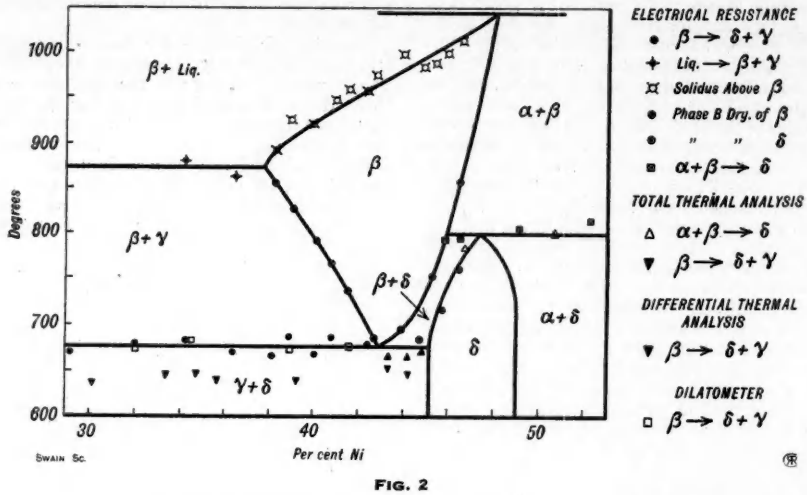



FIG. 2

annealing for thirty minutes at 850 deg. Cent., followed by quenching, can hardly be regarded as sufficient for deducing the β+γ/γ boundary at 850 deg. Cent. In addition, the photographs reproduced are generally poor.

These criticisms are based on the facts given in the paper. It may be that further annealings were carried out, and that the results obtained are more trustworthy than would appear from the above discussion; but if this is the case there is no evidence of it in the paper.

The most careful part of the work appears to be the determination of the boundaries of the β field, which was done mainly by electrical resistivity measurements. The results obtained are replotted, from the author's tables, in Fig. 2, and his descriptions of the various boundary lines are given in the legend. Some of these are a little curious; for example, he refers to the lines separating the β phase from the β+γ, β+δ, and β+α areas as the "phase boundary of β," while that separating β from β+ liquid he calls the "solidus above β." These terms are doubtless correct, but the distinction seems unnecessary. This, however, is but a trifle, and, except for the β/α+β boundary, this part of the diagram can be said to be satisfactorily determined. A few more points on this line would have been advisable. The δ/α+δ phase boundary does not appear to have been determined at all except from the microstructure of one alloy at room temperature.

One remark must be made about the electrical resistivity curves. In Fig. 3 the curve for an alloy containing 36·27 per cent. Ni is reproduced. No explanation is given of the extraordinary break in this curve between 700 and 800 deg. Cent., which seems to the reviewer to be quite meaningless. Several of the other curves show a similar, though less marked, break.

Magnetic analysis of the alloys rich in nickel and The structure of β was determined on quenched and polished specimens, and the author states that some change may have occurred during the operation and that he hopes to redetermine the structure of this phase at high temperatures.

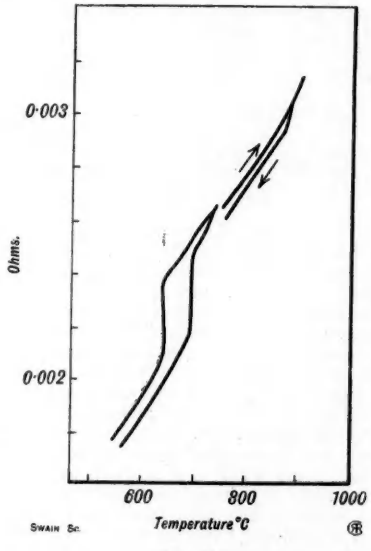



FIG. 3

No evidence appears to have been found for the occurrence of any of the alleged allotropic transformations in zinc.

In conclusion, it may be said that while the work,

or at any rate the results of the work as presented in the paper, are open to serious criticism, there is no doubt that Mr. Tamaru has considerably advanced our knowledge of the constitution of a complicated series of alloys.

## Tungsten Carbide Brinell Balls.

Although the Brinell test is extensively used for hardness determinations, it is not satisfactory for testing materials with a hardness in excess of 600, because of the deformation of the ball. This limitation has been surmounted in some machines, such as the Vickers and the Firth, by the use of pyramidal diamond indenters. With work-hardened balls Hultgren obtained results up to 650 Brinell reproducible to within 1 per cent., while Quick and Jordan with iron-carbon-vanadium balls obtained some further improvement.

Sintered tungsten carbide alloys, which are being used to an increasing extent in applications where extreme hardness is desired, are amongst the hardest of modern metallurgical products, and it is not surprising therefore to find that attempts have been made to produce Brinell balls in these materials with the object of extending the useful range of the test. Recently tungsten carbide balls have been produced in America accurate to within 0·000025in. for diameter and sphericity by grinding rough ball blanks with variations in diameter of several thousandths of an inch.

A comparison has been made by H. Styri of Brinell numbers obtained with such Carboloy balls, Hultgren balls, and Rockwell diamond cone numbers and Vickers diamond pyramid numerals, the results being published in the December issue of *Metals and Alloys*. The specimens tested consisted of ¼in. thick discs cut from the same bar of steel containing 1 per cent. carbon and 1·5 per cent. chromium, quenched from 850 deg. Cent. and reheated to different temperatures. Tantalum carbide constituted an additional sample. Both the Hultgren and Carboloy balls were 5 mm. in diameter and, in making the tests with these balls, one test on a disc was made and the diameter of the impression measured to the nearest 0·01 mm. The permanent deformation of the ball was measured with an optimeter and estimated to the nearest 0·00001in. After the first impression ten more impressions were made on the same disc with the same part of the ball. The total of the eleven readings was averaged and the total permanent deformation of the ball measured after the eleventh reading. A new ball was used for the tests on each separate disc. Some of the results obtained are given in the accompanying table, from which it will be seen that in the higher ranges of hardness values the Carboloy balls suffered appreciably less deformation than the Hultgren balls, and in consequence gave higher Brinell values. The impressions made with Carboloy balls were much more distinct than those produced by Hultgren balls, especially on hard materials. The latter failed completely on tantalum carbide, giving hardness values less than those obtained on some of the steel samples. With the Carboloy balls on tantalum carbide good impressions were obtained, and after eleven determinations the ball deformation was 0·014 mm. Over the range 46 to 62 Rockwell, values obtained with 5 mm. Hultgren balls practically coincided with the Brinell hardness-Rockwell " C " hardness correlation curve published by Petrenko, which was derived from results obtained with 10 mm. balls and 3000 kilos. load on a variety of samples. Petrenko's curve was plotted from his empirical equation and his individual values are within ±10 per cent. of the curve. The average results obtained with the Carboloy balls were consistently higher than those obtained with the Hultgren balls and the differences increased with increasing hardness, but the values did not exceed those of Petrenko's curve by more than 10 per cent. The deformation of the Carboloy balls on the harder variety of steel was comparatively small, for it was found that results obtained on soft steel with a ball used for 100 indentations on a hard steel were not much lower than those obtained with new balls. The results on softer samples with a ball previously used ten times on tantalum carbide, however, were definitely lower. On hard steel Carboloy balls flattened to about half the extent of Hultgren balls, but yielded appreciably higher Brinell values, a result which, it is suggested, may be due to the higher modulus of elasticity of the material. Because of the deformation which takes place the Carboloy balls should not be used on material exceeding 67 Rockwell, or about 730 Brinell, and Hultgren balls should not be used on material exceeding 62 Rockwell or about 660 Brinell. It is of interest to note that Carboloy balls have been used for testing hardness at temperatures up to about 930 deg. Cent. without any softening being observed. Curves relating diamond pyramid results obtained on the Vickers machine with Brinell results obtained with the two types of ball and Rockwell " C " values show very clearly that the results with Carboloy balls are more nearly proportional to diamond pyramid values than are the others.

There is no doubt that the use of such a material as sintered tungsten carbide extends the useful range

| Specimen No. .. .. .. .. | 6 | 7 | 1 | 2 | 8 | 3 | 4 | 5 | Tantalum carbide. |
|---|---|---|---|---|---|---|---|---|---|
| Tempered at deg. Cent. .. .. | 550 | 490 | 425 | 350 | — | 170 | n.t. | n.t. | |
| Vickers P.N., 30 kilos. .. .. | 392 | 480 | 520 | 595 | 675 | 758 | 910 | 900 | 1110 |
| Rockwell " C," 150 kilos. .. | 38·1 | 46·1 | 49·3 | 54·4 | 58·2 | 61·8 | 66·7 | 66·4 | 70 |
| 5 mm. Hultgren ball, 750 kilos., average of 11 tests, B.H. No. | 378 | 454 | 485 | 548 | 604 | 655 | 709 | 698 | 694 (one impression) |
| Ball deformation after 11 tests, mm. | — | — | 0·0012 | 0·0037 | — | 0·0075 | 0·015 | 0·014 | — |
| 5 mm. Carboloy ball, 750 kilos., average of 11 tests, B.H. No. | 378 | 460 | 495 | 571 | 635 | 700 | 792 | — | 820 |
| Ball deformation after 11 tests, mm. | — | — | 0·0017 | 0·0027 | — | 0·005 | 0·009 | — | 0·014 |

of the Brinell test, by eliminating the errors, up to a certain limiting hardness, which result from the use of softer balls.

The upper limit claimed, however, is only 67 Rockwell or about 730 Brinell. Accepting 600 Brinell as the upper limit of hardness which it is possible to determine satisfactorily with an ordinary hardened steel ball, the extension of the range resulting from the use of sintered tungsten carbide balls amounts but to 130 points, which after all is not a large increase. On the other hand, the diamond pyramid test, which is already widely used, is suitable for determining greater hardness, and, moreover, the results are independent of the applied load. The test is also quite satisfactory for soft material and is no more difficult to carry out than the Brinell test.

## Inverse Segregation.

By H. SUTTON, M.Sc.

No. I.

SEGREGATION in alloys is of high importance in various processes of production and manufacture. Exacting specifications and the need of technical processes have stimulated those engaged upon the task of producing materials of uniform composition. The subject is of importance in steels, alloys of the noble metals, and in a large number of non-ferrous alloys. In steels segregation of constituents present in only small percentages is of importance, and special attention has been paid to segregation of non-metallic constituents. The reports of the Committee on Heterogeneity of Steel Ingots[1] indicate the degree of attention now being paid to segregation in steel ingots and provide useful data illustrating the extent to which it may occur.

Two kinds of segregation are recognised in cast alloys. The first, or "normal segregation," produces an ingot or casting in which the concentration of the constituent or constituents of lower melting point increases towards the central portions. It is usually attributed to the fact that in the freezing process the first crystals to separate from the liquid are richer in the constituent of higher melting point, leaving the liquid portion richer in the constituent of lower melting point.

In the second type, or "inverse segregation," the outer portions are richer in the constituent of lower melting point than the central portion. The term "liquation" has also been used for this form of segregation.

Other forms of segregation are recognised as of importance in their effects on the structure and properties of alloys; for instance, that form due to instability of minute crystals of a substance in presence of a solvent and larger crystals of the same kind, to which the formation of globular cementite in hyper-eutectoid steels is attributed. Another, and perhaps similar form, is that which results in the occurrence of masses of a particular constituent at the boundaries of crystals, themselves sometimes substantially free from inclusions of the same constituent. This occurs in alloys of the duralumin type, in austenitic steels, &c. Research indicates that in some forms of segregation the effects observed arise from the processes of solidification and diffusion, and are readily explained by existing knowledge. In the inverse form of segregation the non-uniformity of distribution is the opposite of that which would be predicted from a simple consideration of the equilibrium diagram, and many explanations have been advanced.

Much credit is due to S. W. Smith for his early and lucid publications on the subject.[2] Bauer and Arndt[3] recognise that segregation may be inverse or normal, according to the relationship between three factors—

(*a*) The velocity of crystallisation of the primary dendrites;

(*b*) the particular direction of the axes along which the crystals grow;

(*c*) the velocity of diffusion of one component into another.

They acknowledge that an intense temperature gradient between the outside and the centre of the ingot and a long solidifying range of the alloys are important factors in determining the type of segregation. In their conception of inverse segregation voids occur between the primary crystals formed on the outside of the casting, and into these voids the still liquid metal passes, losing concentration in the higher melting constituent as it travels, and finally freezing as eutectic.

In two of his early publications on the subject, Masing[4] attributes the phenomena of inverse segregation to under-cooling of the alloys, and supersaturation of the primary crystals in the outer skin with respect to the more fusible component. He has studied the volume changes in alloys during solidification, and points out that the alloys which expand most during slow solidification segregate inversely on rapid cooling, while no segregation is observed in those which expand either slightly or not at all during the cooling process.

In the case of bronze, Kühnel recognised the same outward movement of the fluid rich in tin that had been observed by Bauer and Arndt, but came to a different conclusion, *i.e.*, that the hydrostatic pressure exerted by the shrinkage of the outer shell on cooling causes a squeezing out of the tin-rich mother liquor into the outer layers of dendrites. This process was considered to be the cause of inverse segregation.

Jokibe[5] investigated the solidifying range and inverse segregation in copper-zinc alloys containing less than 40 per cent. of copper, and confirmed the apparent expansions in slowly cooled alloys observed earlier by Turner and Murray. The expanded alloys showed low hardness and elastic limit, and contained cracks and voids. Turnings from the expanded alloys showed higher density than the castings, and the density values were increased by standing *in vacuo*. The inverse segregation observed was proportional to the expansions and the expansions were greatest in sand-cast bars.

Genders[6] studied inverse segregation in chill cast slab ingots in 5 per cent. tin-bronze and 70 : 30 brass, and observed that in extreme cases of inverse segregation, exudation at the surface of the casting occurs simultaneously with the escape of dissolved gases. In these cases Genders considers that owing

[1] First Report, Committee on Heterogeneity of Steel Ingots *J.*, Iron and Steel Inst., 1926, 113, 39–151.

[2] S. W. Smith, *Journ.*, Inst. Met., 17 (1917), 65–103; S. W. Smith, Bull., Inst. Min. Met., 1926, No. 257.

[3] Bauer and Arndt, Zeits. Metallk., 13 (1921), 497–506, 559–564.

[4] Masing, Zeits. Metallk., 14 (1922), 204–206, and 17 (1925), 251–257.

[5] Jokibe, *Journ.*, Inst. Met., 31 (1924), 225–241.

[6] Genders, *Journ.*, Inst. Met., 37 (1927), 241–271.

to the pressure of the liberated gases residual liquid is expelled from the central region towards the surface of the casting or ingot. The discussion of this useful paper brought forward several remarks of special interest, and in particular those of Archbutt, which described an experiment made on the suggestion of Rosenhain. An ingot in aluminium alloy containing 12 per cent. of copper was bled soon after being cast, the remaining hollow shell being only ¼in. to ½in. thick, but 3in. in outside diameter. The shell showed higher copper content on the outside (12·27 per cent.) than the inside (11·57 per cent.). These observations have provided food for serious thought for all students of the subject.

More recently Woronoff[7] has studied the occurrence of inverse segregation in duralumin. Segregation occurs in technical aluminium and its alloys in different forms, *e.g.*, exudations at the surface of cast ingots and on rolled bars of commercial aluminium. In the latter case the exudations are richer in iron and silicon than the normal material. A study of the composition of exudations from different alloys showed that the composition approaches that of the eutectic of the system concerned. By raising the casting temperature the degree of inverse segregation is reduced, and this is attributed by Woronoff to the longer freezing time and consequent diffusion within the solid solutions. When the alloy is poured into heated iron moulds the degree of inverse segregation is reduced. In this case the pre-heated moulds result in lower copper content in the exudations than is observed with water-cooled moulds. In the experiments on casting temperature only, high casting temperatures lead to a higher percentage of the lower melting constituents in the exudations, probably because the longer time of freezing permits the mother liquor to attain a higher concentration in these constituents before it passes to the external parts of the ingot. Woronoff suggests that in his experiments on the influence of mould temperature only, the main effect is upon the freezing conditions of the outer zones. In passing to the outer zones the mother liquor reacts with the crystal skeletons already formed, depositing its higher melting constituents. Its content of the inversely segregating component therefore steadily rises while the quantity of liquid falls. Reduction of rate of pouring favours the inverse segregation, by improving the cooling conditions of the melt. Experiments by Woronoff with chills of varying ratio of wall thickness to billet diameter indicate a decrease in degree of inverse segregation with increase of wall thickness of mould. In sand castings inverse segregation is comparatively slight. Woronoff recognises movement of the crystals against the mother liquor and internal pressure, manifested by exudations from the surface of castings. While he observes no definite evidence of an expansion of the mother liquor during freezing, he regards this as possible. Diffusion is regarded by him as a counter effect tending towards uniformity of composition. As practical aids to minimising inverse segregation in duralumin Woronoff recommends :—

(1) Reduction of the percentages of inversely segregating elements, thereby shortening the freezing interval.

(2) Reduction of differences in freezing conditions at edges and centre, achieved by overheating the melt somewhat and pre-heating the chill mould, which should be of suitable ratio.

(3) Removal of the outer layer containing exudations, from cast ingots, slabs, or billets before or after hot rolling.

Bohner[8] has employed some novel methods in his study of segregation in an aluminium-copper alloy containing 5 to 6 per cent. of copper. The molten alloy was cast into taper moulds made of 6 mm. iron sheet with welded joints. The ingots were 195 mm. in diameter at the top and 165 mm. at the bottom and had the form of an inverted truncated cone. Wide variation in rate of cooling was obtained by placing the mould in large baths of water or of salt at various temperatures. As the salt employed was a mixture of sodium and potassium nitrates, a wide range of temperatures of the cooling medium could be employed. Bohner points out that the salt mixture probably has about the same value of thermal conductivity as certain forms of sand mould. When the ingots had cooled to about 500 deg. Cent. they were cooled off in cold water, which would tend to minimise diffusion effects in the frozen alloy. In these experiments the temperature of the nitrate bath or water bath was kept uniform by intensive agitation. As the heat capacity of the cooling bath was large in relation to that of the metal, the possibility of increase in temperature of the mould wall during casting was practically precluded. The solid ingots were sectioned and drillings taken from ten different but definitely located positions on each section for the determination of the copper content. The results obtained indicate that :—

(1) With chill temperatures of 230 deg. Cent. or lower inverse segregation of copper occurs.

(2) With chill temperatures of 300 deg. Cent. and over the copper segregates normally, *i.e.*, the outside contains less copper than the middle.

Thus, under the conditions of the experiments, the change from inverse to normal segregation occurs at a mould temperature between 230 deg. and 300 deg. Cent.

Bohner's results on ingots cast in this way also show that where inverse segregation occurs its degree as indicated by the difference in copper content at the surface and the centre is least in the most rapidly cooled ingots. In the ingots showing normal segregation the difference in copper content between outside and centre is smallest in those cast in the hottest moulds and Bohner mentions that with high mould temperature there are better facilities for diffusion and levelling up of differences in composition.

In some further experiments Bohner used slightly different arrangements with the same sheet iron mould. For cooling the mould a salt bath somewhat larger than the mould was used. The salt bath was placed in a gas-fired furnace and could be heated to any desired temperature. Thermo-couples were provided for measurement of mould and metal temperatures during freezing. When the desired mould temperature had been attained and held constant for some time, the molten alloy was poured until the surface of the metal in the mould was about 20 mm. below that of the salt outside. During cooling the maximum temperature of the mould was observed. As in the previous experiments, the mould was taken out of the salt bath and cooled rapidly with the ingot in cold water. The variation in cooling rate resulting from the use of different initial temperatures of the salt is illustrated by the time intervals for cooling from 640 deg. (melting point of the alloy) to 520 deg.

[7] Woronoff, Zeits. für Metallk., Sept., 1929, Vol. 21, No. 9, pp. 310–316.

[8] Bohner, Hausz. der V.A.W., Jan./Feb., 1932, pp. 24–30.

Cent., which were eleven minutes with an initial mould temperature of 230 deg. Cent., thirty minutes with an initial mould temperature of 300 deg. Cent., and sixty minutes with an initial mould temperature of 500 deg. Cent. As a result of the rapid increase in mould temperature at the commencement of casting, a condition not present in the earlier experiments, normal segregation has begun with a mould temperature of 230 deg. Cent. As in the previous experiments, the degree of normal segregation becomes smaller with increasing mould temperature. Under the modified conditions of cooling the differences in copper content between centre and outside for a mould temperature of 500 deg. Cent. are appreciably smaller

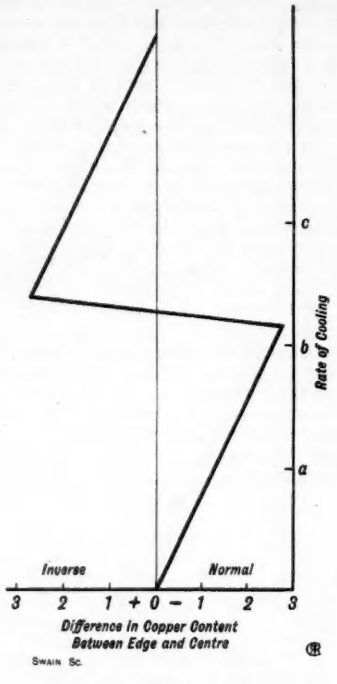



FIG. 1

than when the alloy was cast in the same mould maintained at a constant temperature of 500 deg. Cent., the observations thus indicating clearly the influence of diffusion.

In some further experiments Bohner fitted to the sheet iron moulds iron jackets, the space between mould and jacket, which gradually becomes smaller from the top downwards, being filled with asbestos for insulation. A short portion of the mould from the bottom upwards remained without covering. The conditions of cooling were varied by changing the dimensions of the jackets, and using still or agitated water to cool the portion of the mould below the jacket. In several cases the ingots were fed as in industrial practice. In all these experiments the copper content was found to be higher at the centre of the bottom than at the centre of the top. The ingot cast with the highest degree of insulation showed normal segregation at all levels, but all the others showed inverse segregation irrespective of the degrees of side insulation and bottom cooling. Increasing the degree of bottom cooling without varying the degree of side insulation resulted in a diminution in the copper content differences between samples taken from outside and centre at equal heights. Feeding of the ingots did not appear to affect the segregation appreciably.

Bohner concludes his investigation with two experiments on the lines of that of Archbutt, to which reference has already been made. In the first, the sheet iron taper mould was immersed in a tank of strongly agitated water during the casting and cooling of the ingot, but the residual liquid was poured out after a sufficiently thick layer had frozen. In the second experiment the mould was placed in a salt bath heated to 350 deg. Cent., and, as in the previous experiment, the residual liquid was poured out before freezing was complete. The hollow ingots were sectioned and drillings from various positions analysed. In the case of the bled ingot which had been cooled rapidly, the outside samples had a higher copper content than the residual liquid, and samples taken nearest the centre had about the same copper content as the residual liquid, the observations confirming those of Archbutt. On the other hand, the slowly cooled bled ingot showed no inverse segregation, the samples taken from the outside all containing less copper than the residual liquid.

In summarising his work Bohner states that inverse segregation in aluminium-copper is essentially a function of cooling velocity. With indefinitely slow cooling no appreciable variations in copper content are observed as full opportunities for complete diffusion are present. When the time of freezing is fairly long, normal segregation of copper occurs, *i.e.*, the edge has lower copper content than the core. At a definite rate of cooling which can be determined exactly by experiment, a sudden change from normal to inverse segregation occurs, while at higher rates of cooling the degree of inverse segregation becomes progressively smaller, as shown in Fig. 1. Repeated tests by the vacuum method of the liquid aluminium-copper alloy used in the work having shown that the metal was practically free from gas, inverse segregation of aluminium-copper alloys cannot be attributed to dissolved gases.

## High-Phosphorus Copper Alloys.

ALLOYS of metals with high proportions of non-metals such as carbon and phosphorus appear very unpromising engineering materials owing to extreme brittleness in the cast state. That it should be feasible to work them by forging, rolling, &c., has been thought impossible. Research has shown, however, that by special means valuable properties, *e.g.*, hardness, of such materials can be made available for engineering use, and, moreover, that working by pressing, rolling, extrusion, &c., may be practicable. An interesting example of the former case is afforded in the modern cutting material known as Widia, Carboloy, &c., which consists essentially of carbide of tungsten. The extreme hardness of this material has been known for some time, but could not be exploited until the discovery was made that if the finely divided carbide mixed with a small amount of cobalt is compressed and heated to a very high temperature in a neutral atmosphere, a solid mass is obtained of extreme hardness and sufficiently tough to act as a cutting tool of remarkable capabilities.

The practicability of rolling, pressing and extruding materials of the above kind has recently been demonstrated in the case of brittle alloys of copper and phosphorus. In 1931 Ellis read a paper before the Institute of Metals describing the production of

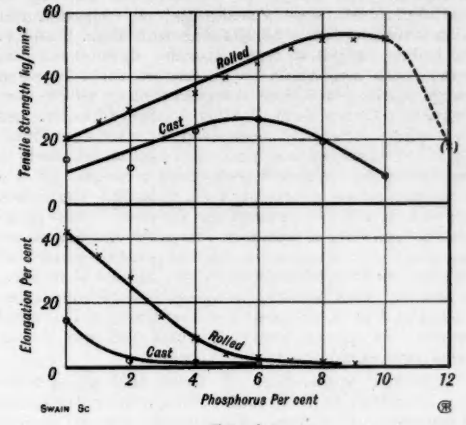



FIG. 1

rolled strip 0·015in. thick, containing 5 per cent. phosphorus. To avoid fractures and flying chips he used small highly chilled strip ingots—6 × 1 × 0·25in. cast in chill moulds—and great caution in rolling, using light pinches with reheating between each pass. After hot rolling in this way to 0·040in. or 0·02in. thick, the strip could be finished cold. Temperatures from 650 deg.–450 deg. Cent. were used. A heavy scale gave trouble at 650 deg. Cent., and the lowest temperature, 450 deg. Cent., seemed most suitable. In his paper Ellis states that it is extremely difficult, if not impossible, to roll the alloys with more than 6 per cent. phosphorus, but a footnote records that the 10 per cent. alloy had subsequently been successfully rolled to strip.

More recently a detailed investigation into these interesting alloys has been described by Buckhardt,

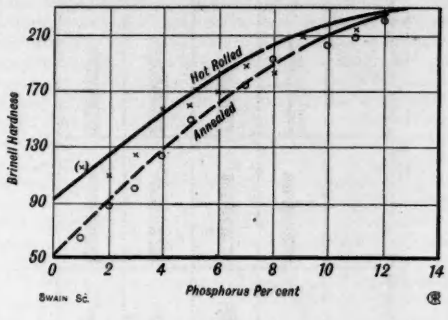
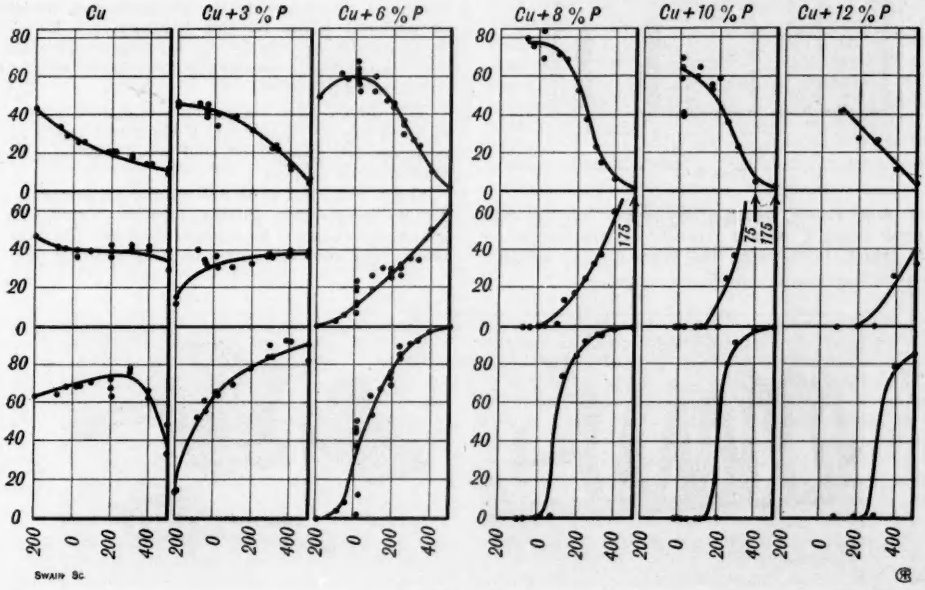



FIG. 2

Linicus and Sachs.* These investigators were concerned with the production of materials resistant to attack by chemical reagents. After successfully producing wrought articles, *e.g.*, rod, tubing, pump parts, &c., in phosphorus-copper alloy, they investigated the possibility of working other brittle alloys of copper, *e.g.*, with arsenic, antimony, and silicon




FIGS. 3 AND 4

respectively, and alloys of nickel with phosphorus. They record that the arsenic-copper and antimony-copper alloys behaved like phosphorus-copper and

* *Metallwirtschaft*, June, 1932.

that it was possible to work the silicon-copper and phosphorus-nickel alloys, although with greater difficulty, at higher temperatures. According to

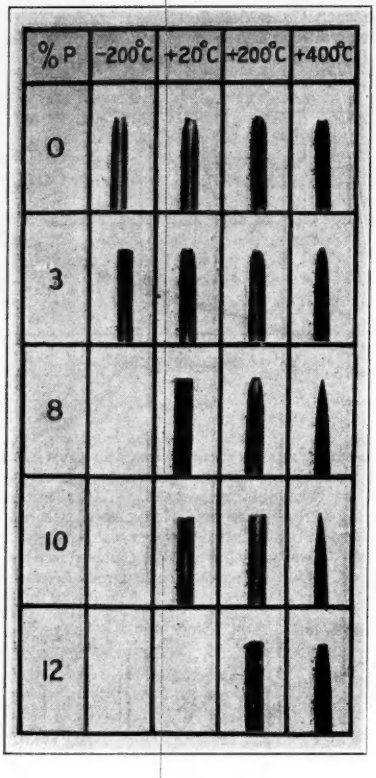



FIG. 5

Heyn and Bauer, phosphorus-copper alloys with 14·1 per cent. P consist entirely of the compound $Cu_3P$, which forms with the copper solid solution (extruded) easily above 300 deg. Cent., but below this temperature they very rapidly become brittle. The improvement in tensile strength and extensibility through rolling is shown in Fig. 1. Hardness rises steadily with increasing phosphorus content, as shown in Fig. 2. The tensile properties from 200 deg. to 500 deg. Cent. were investigated on extruded rod with the remarkable results shown in Figs. 3 and 4. In brittle ranges it was naturally difficult and in some cases impossible to obtain fractures between gauge marks. It will be observed that up to 300 deg. Cent. the 12 per cent. P alloy is highly brittle. As this alloy is chiefly composed of the compound $Cu_3P$ it would appear that the compound itself is highly brittle over this temperature range. It is a remarkable and interesting fact, therefore, that when present in smaller amount in alloys of lower phosphorus content, it actually increases the toughness and plasticity of copper in this temperature range and beyond, to the pronounced extent indicated in Figs. 3 and 4. This remarkable effect is strikingly illustrated in Fig. 5, showing the flow cones of fractured tensile test pieces, some of which indicate plastic behaviour analogous to that of glass.

Practical application of these high-phosphorus copper alloys will be found where their particular properties are of use. Phosphorus content should not exceed that of the eutectic (8·3 per cent.) beyond which brittleness becomes too great. The investigators forecast improved properties by admixture of other metals.

The alloys near the eutectic are already known as good hard solder, having relatively low melting point and good fluidity exceeding that of silver solder. The new knowledge of their workability offers prospects of improving the strength and toughness of soldered joints by hot hammering. Moreover, in place of very brittle cast stick the solder can be made available in practically any size of rolled strip or extruded wire.

The alloys have remarkable chemical properties. Beyond about 7 per cent. P their resistance to hot concentrated phosphoric acid is substantially higher than that of copper.

Sheet, rod, and tube are readily produced and as readily worked into articles of various kinds. Photographs are shown of hot-pressed beakers, and a cooling worm produced by extrusion and bending (Fig. 6),

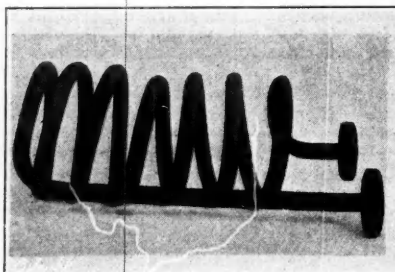


FIG. 6

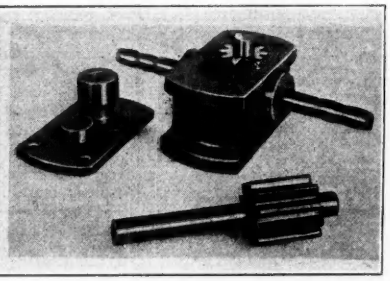


FIG. 7

an eutectic alloy at 8·3 per cent. P. Buckhardt, Linicus and Sachs find that the alloys with phosphorus content higher than the eutectic and almost up to that of the compound, can be hot rolled and pressed and a cog-wheel pump made of forged and pressed parts (Fig. 7), all in 8 per cent. P alloy. Machining properties are very good. In use, articles such as those above mentioned are very hard and strong,

though rather sensitive to shock. The strength of this alloy (8 per cent. P) is about three times as great as that of ordinary cast iron.

## White Bearing Metals.

REFERENCE was made in the December, 1932, issue of THE METALLURGIST to the first portion of a monograph by Dr. Ernst Fleischmann on "White Bearing Metals." The second portion, dealing with the physical properties and frictional tests of white metals, is valuable on account of a large number of graphs and tables embodying the results of tests carried out by the author on an extensive series of white metals.

Most of the alloys studied are comprised in the list of standard German white metals shown, with their compositions, in Table I.:—

TABLE I.

| Mark. | Tin. | Antimony. | Copper. | Lead. |
|---|---|---|---|---|
| | | | | Per cent. |
| WM 80 F .. .. | 80 | 10 | 10 | — |
| WM 80 .. .. .. | 80 | 12 | 6 | 2 |
| WM 70 .. .. .. | 70 | 13 | 5 | 12 |
| WM 50 .. .. .. | 50 | 14 | 3 | 33 |
| WM 42 .. .. .. | 42 | 14 | 3 | 41 |
| WM 20 .. .. .. | 20 | 14 | 2 | 64 |
| WM 10 .. .. .. | 10 | 15 | 1·5 | 73·5 |
| WM 5 .. .. .. | 5 | 15 | 1·5 | 78·5 |

Other white metals, the compositions of which are given, are: "English bearing metal," containing 93·11 per cent. tin, 4·24 per cent. antimony, 2·7 per cent. copper, and 0·11 per cent. iron; "Einheitsmetall," with 10 per cent. tin, 15 per cent. antimony, and 75 per cent. lead; "Thermit" metal, containing 4 per cent. tin, 20 per cent. antimony, 1 per cent. copper, 72 per cent. lead, and 3 per cent. nickel; and "Bahnmetall," having the composition 98·67 per cent. lead, 0·72 per cent. calcium, 0·57 per cent. sodium, 0·04 per cent. lithium.

A compression test can provide useful data for a comparison of different white metals. The compressive strength is defined as the load in kilogrammes per square millimetre applied to the end of a cylinder which produces visible cracks in the sides, while a measure of the plasticity is given by the percentage reduction in height at this stage. Unfortunately, the author does not specify the dimensions of the test cylinders which he employed. Obviously, the compressive strength should be considerably greater than the maximum pressure which the bearing metal is to encounter in service, while the plasticity provides an indication of the capacity of the metal to withstand impacts and irregular loading, and to adapt itself to the contour of the journal. The results of these tests are given in Table II.

The maximum compressive strength and plasticity are found in the white metals containing the highest proportions of tin, as far as the "straight" tin-antimony-copper-lead alloys are concerned, but in these respects the lead-base metals with only 5 and 10 per cent. of tin are superior to those of intermediate tin content. The strength in compression and the plasticity of "Thermit" and "Bahnmetall" are said to be equal to those of the expensive tin-base metals; both these are lead-base alloys, the former containing 3 per cent. of nickel, while the latter is hardened by calcium and other alkali and alkaline earth metals.

The specific gravity of a white metal is an important consideration; a heavy alloy is undesirable for two reasons—first, because more metal has to be bought to fill a given bearing, and secondly, because the bearing may form part of a reciprocating member, the weight of which should be reduced as far as possible.

The Brinell hardness is the physical characteristic which is most often quoted in connection with white metals—no doubt because this is the most easily determined property. It is generally recognised, however, that the hardness gives only a rough indication of the bearing properties. At the same time, Dr. Fleischmann finds that in the standard white metals the value as a bearing metal is approximately proportional to the Brinell hardness, but that this does not apply to "Thermit" metal. Since the great majority of bearings operate at more or less elevated temperatures, either on account of heat developed by friction at the surface of the journal, or because of the conduction of heat to the bearing along the journal, or from the surroundings, it is desirable to know the properties of bearing metals at these temperatures. As is shown in Table II. the Brinell hardnesses have been determined for eleven white metals at room temperature and also at 50 deg., 75 deg., and 100 deg. Cent. The two alloys containing 80 per cent. of tin are the hardest of all the metals examined at all temperatures, but at 100 deg. Cent. the two lead-base alloys, "Thermit" and "Bahnmetall," of which the former contains

TABLE II.

| Alloy. | Spec. gravity. | Comp. str. kilos./mm.² | Red'n in ht., %. | Brinell hardness numbers. | | | |
|---|---|---|---|---|---|---|---|
| | | | | 15 deg. Cent. | 50 deg. Cent. | 75 deg. Cent. | 100 deg. Cent. |
| WM 80 F .. .. .. .. | 7·5 | 18·0 | 35·5 | 38 | 25·9 | 22·0 | 16·0 |
| WM 80 .. .. .. .. .. | 7·5 | 16·8 | 35·5 | 38 | 25·7 | 21·8 | 15·7 |
| WM 70 .. .. .. .. .. | 7·7 | 15·3 | 39·0 | 35 | 24·1 | 20·5 | 13·0 |
| WM 50 .. .. .. .. .. | 8·2 | 10·2 | 21·5 | 24·4 | 20·0 | 13·4 | 10·3 |
| WM 42 .. .. .. .. .. | 8·5 | 10·1 | 18·0 | 27 | 20·3 | 16·0 | 10·1 |
| WM 20 .. .. .. .. .. | 9·4 | 11·1 | 19·5 | 28·4 | 20·6 | 14·7 | 11·1 |
| WM 10 .. .. .. .. .. | 9·7 | 12·5 | 22·5 | 30·2 | 22·7 | 20·0 | 11·6 |
| WM 5 .. .. .. .. .. | 10·1 | 11·8 | 25·5 | 26 | 20·3 | 14·5 | 11·8 |
| "English" .. .. .. .. | — | — | — | 19·7 | 16·4 | 12·1 | 8·9 |
| "Thermit" .. .. .. .. | 9·8 | 17–18 | 35–38 | 27·2 | 22·0 | 18·6 | 13·8 |
| "Bahn" .. .. .. .. | 10·56 | 17–20 | 25–30 | 27·8 | 18·5 | 16·4 | 14·2 |

only 4 per cent. of tin, and the latter is tin-free, are second only to the 80 per cent. tin metals. The friction tests, described later, provide an interesting comparison with these hardness results. For example, the alloys of intermediate tin content, which have the lowest Brinell hardnesses, show the poorest performance in the friction test. On the other hand, the "English" white metal, which is throughout softer than any of the other metals, is found to be an excellent bearing metal, both in laboratory and service running tests. It is evident, therefore, that even when determined at elevated temperatures, the Brinell hardness cannot be used as a conclusive guide to the behaviour of a white metal in a bearing.

Hardness is certainly an important factor in the wearing properties of a bearing metal, although here, again, running tests do not reveal any simple connection between the two; indeed, it is by no means unknown for the softer of two white metals to show the least wear when operating with the same journal under identical conditions of load, speed,

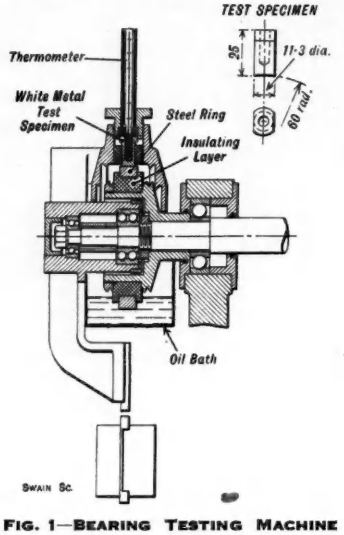



FIG. 1—BEARING TESTING MACHINE

and lubrication. The author points out that the ideal bearing metal would wear rapidly at first, so as to permit quick "running in," and then the rate of wear would fall to a minimum. In any event, the bearing metal should never be capable of wearing the shaft, but if the shaft has become scored through the entrainment of abrasive material in the oil, the white metal ought to assist in repolishing it.

The machine used for friction tests, based on an earlier design by Borofsky, possesses some unusual features. The general arrangement is shown in Fig. 1. The specimen of white metal takes the form of a cylinder 25 mm. long and 11·3 mm. in diameter (giving a bearing area of 1 square centimetre), which is pressed by a calibrated spring against a rotating steel ring. The ring is mounted on a spindle, from which it is thermally insulated, however, by a layer of non-metallic material. The specimen is similarly insulated on the sides, so that as much as possible of the heat generated at the rubbing surface is retained in the white metal. Means are provided, as shown in the sectional drawing, for measuring the temperature attained by the specimen, while the bearing pressure can be varied by adjustment of the spring, and the speed of rotation is controlled through the driving motor. The coefficient of friction is determined from the angular displacement of the pendulum, which results from the frictional torque. Lubrication is provided by an oil bath, in which the lower portion of the ring runs continuously.

Our knowledge of the factors governing the performance of a bearing is at present so imperfect that any running test must be regarded as very largely empirical, and in these circumstances the logical course to follow in designing a bearing testing machine would appear to be to try to reproduce, as closely as possible, the conditions likely to prevail in service. When viewed in this light the machine used by the author is open to considerable criticism. In the first place the area of white metal bearing on the journal is very small in comparison with the total area of the latter. This arrangement eliminates to a large extent one very important factor, which varies for different bearing metals, namely, the capacity for establishing and retaining under heavy pressures a continuous film of oil extending over the whole of the bearing surface. It is well known, moreover, that the formation of the oil film is also influenced by the angle and depth of the chamfer on the leading-in side of a half-bearing. It would be impossible to reproduce this feature in Dr. Fleischmann's machine owing to the small area of the bearing surface, which also has the serious disadvantage that the danger of the bearing rocking on the journal is increased.

A second criticism of the author's arrangement is that the precautions taken to insulate the specimen from the main portion of the machine introduce a condition which is not encountered in service. As a result of this interference with the free flow of heat away from the bearing surface along the shaft and through the housing the specific heat of the white metal acquires a fictitious importance, or perhaps it would be more correct to refer to the heat capacity of the specimen, since the effect of a low specific heat might be compensated by a high specific gravity. The exaggeration of these factors is all the more undesirable because in this test the criterion by which the various white metals are compared is the temperature attained by the specimen when the bearing is running under prescribed conditions of pressure and speed.

Bearing in mind these limitations, we may consider the chief results obtained. Table III. shows the final steady temperatures attained by specimens of various white metals when running under different combinations of load and speed, while Figs. 2 and 3 reproduce the graphs of temperature against time for the high-tin, lead-free alloy WM 80 F, and the lead-base "Thermit" metal. It will be seen that the maximum pressure employed was 1138 lb. per square inch, and the maximum rubbing speed 39·4ft. per second, giving a $p/v$ value of 44,837, which is by no means uncommon in modern engine practice.

The curves seen in Fig. 2 are typical of those obtained in all tests except in the cases of alloys WM 42, "Einheitsmetall," "Bahnmetall," and "Thermit" under the highest $p/v$ values. In the first three of these the temperature did not settle down to a steady value below 100 deg. Cent. when the load and speed were at the maximum, while "Thermit" was peculiar in that, with a $p/v$ of 44,837, the temperature rose to an abnormally high degree before attaining the lower final steady value. This feature is clearly evident in Fig. 3.

According to the German author's data, and judging by the temperatures recorded under the maximum $p/v$ values, the alloys fall in the following order of decreasing superiority :—

WM 80 F, WM 10, "English," "Thermit," WM 80, WM 20, WM 80 (coarse-grained), WM 70, WM 5, pure tin, antimonial lead, WM 50, "Bahnmetall," WM 42, "Einheitsmetall."

This list makes surprising reading to any metallurgist who has the opportunity to observe the behaviour of various bearing metals in service, and it would be difficult to convince him that Dr. Fleischmann's data provide a reliable guide for the selection of a white metal required to operate in a bearing under given conditions of loading and speed. For example, thousands of bearings lined with metal corresponding closely in composition to WM 42 are giving satisfactory service under conditions where an alloy such as WM 10 would fail rapidly through excessive wear and squeezing out, and yet the results shown in Table III. would suggest that, at all except the lowest speeds and loads, alloy WM 42 would overheat before WM 10. Similar remarks may be made regarding antimonial lead and pure tin, which would be quite unsuitable for bearings loaded to 1000 lb. per square inch. These observations also rather weaken the case which the author makes out for the nickel-hardened lead-base alloy "Thermit" as a cheap substitute for the more expensive tin-base white metals.

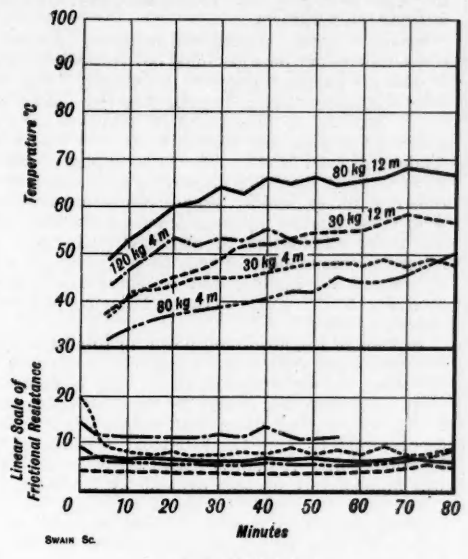



FIG. 2—WM80F.

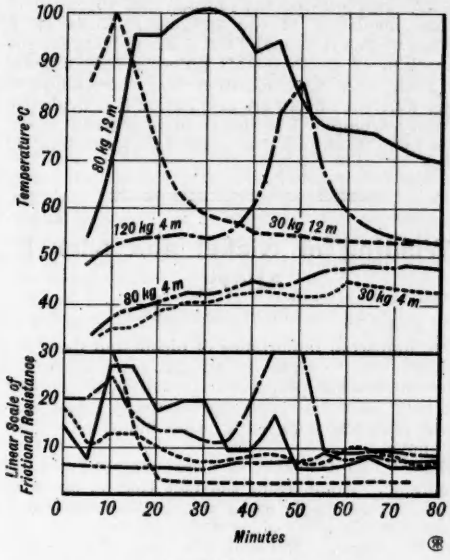



FIG. 3—THERMIT

$p/v$ values :—

| | |
|---|---|
| 120 kg./sq. cm. | = 1706 lbs./sq. in. |
| 80 " " | = 1138 " " |
| 30 " " | = 427 " " |
| 12 m./sec. | = 39·4ft./sec. |
| 3 " " | = 13·1 " " |

TABLE III.—*Frictional Tests : Final Steady Temperature (Deg. Cent.) Attained.*

| Alloy. | $p/v$ ($p$ in pounds per square inch, $v$ in feet per second.) | | | | |
|---|---|---|---|---|---|
| | 1138/39·4. | 1706/13·1. | 1138/13·1. | 427/39·4. | 427/13·1. |
| WM 80 F | 65–67 | 52–55 | 48–50 | 55–60 | 47–49 |
| WM 80 | 70–72 | 50–52 | 49 | 63 | 47–48 |
| WM 70 | 75–80 | 52–53 | 47–48 | 63 | 43–44 |
| WM 50 | 95–100 | 75 | 45 | 62 | 41 |
| WM 42 | Over 100 | 80–82 | 64 | 66 | 45 |
| WM 20 | 75 | 48 | 47 | 63 | 43 |
| WM 10 | 67 | 52 | 47 | 67 | 48 |
| WM 5 | 80–85 | 70 | 52 | 73–75 | 49 |
| "Einheitsmetall" | Over 100 | Over 100 | 53 | 75–80 | 45 |
| WM 80 F, coarse grain | 77 | 53 | 49 | 66 | 48 |
| Tin | 83 | 72 | 53 | 66 | 47 |
| Antimonial lead | 88 | 61 | 57 | 68 | 51 |
| "Thermit" | 68 | 54 | 48 | 54 | 43 |
| "Bahnmetall" | Over 100 | 80 | 50 | Over 100 | 44 |
| "English" | 65–70 | 54 | 53 | 63–65 | 43 |

In all probability these discrepancies between the results obtained on the bearing testing machine and the behaviour experienced in service are to be attributed to the two features of the machine which have already been mentioned, namely, the small area of the white metal specimen in relation to that of the steel ring representing the journal, and the effective thermal insulation of the specimen. Tests on a machine of this type may form a useful basis for the comparison of white metals differing only slightly from each other in composition, but where alloys of widely different nature are in question it is evidently necessary to employ a testing equipment which reproduces more faithfully the conditions prevailing in service.

## Welding of Nickel and Nickel Alloys.

By HERBERT HERRMANN.

THE industrial importance of nickel and its alloys is chiefly due to their exceptional mechanical and corrosion-resistant properties, as well as to the fact that they maintain these characteristics under conditions destructive to many other industrial metals and alloys.

The welding properties of nickel are not nearly as favourable. Apart from the fact that it tends to "work" considerably under local heating and that it passes through a hot-short range between 800 and 1050 deg. Cent. (1450 and 1850 deg. Fah.), fused nickel exhibits a great capacity for absorbing many gases, especially hydrogen, sulphur dioxide, and oxygen. These tend to embrittle and weaken the metal, hydrogen by separating during solidification, forming porous welds, sulphur and oxygen by combining with nickel, forming sulphides and oxides which precipitate in the grain boundaries, lowering strength and ductility. Oxygen, if present in excess, tends to form tough and hard films of oxide on the surface of the fused weld, and these are a serious obstacle to the progress of welding, but the formation of these films may be prevented by the application of effective fluxes.

Attention should in this connection be called to the fact that up to a certain percentage of oxides in the weld metal the influence of absorbed oxygen does not appear to be as injurious as has been supposed. Nickel and oxygen form a simple eutectic series, the eutectic containing 0·214 per cent. of oxygen (corresponding to 1·1 per cent. NiO). This percentage of oxide appears to be easily soluble and should not, therefore, be seriously injurious. Only if this percentage is exceeded does it influence the ductility of the weld perceptibly.

Very different conditions prevail in the case of sulphur. The nickel sulphide ($Ni_3S_2$) formed is not dissolved by nickel. It is exceedingly brittle and during solidification separates out along the grain boundaries, transmitting its own brittleness to the weld.

Applying the above considerations to the autogenous welding process, it is obvious that the counter measures employed must be both preventive and curative. It is practically impossible, for this reason, to employ oxy-hydrogen welding for nickel and its alloys, some of the unburned hydrogen entering the fused metal and rendering it porous. Oxy-acetylene welding is the only autogenous process now available for this purpose, although oxy-hydrogen welding may be applied to the "hammer-welding" process of nickel (discussed below). Since in this process the nickel is not heated to fusion, the metal does not absorb gases in sufficient quantities to influence mechanical properties, and the oxy-hydrogen burner may thus be employed for raising the metal to hammer welding temperatures.

Since, however, commercial acetylene frequently contains sulphur, pure gas must be expressly specified. It does not suffice to employ "practically" pure gas. Only absolutely sulphur-free acetylene should be used in the welding of nickel and its alloys, since even traces of sulphur (as low as 0·005 per cent.) will render the weld brittle. The same applies to all the other welding materials employed, including welding rods and fluxes, which, besides protecting the fused weld metal against injurious outside influences, must assist the elimination of absorbed gases, and the injurious compounds formed, from the liquid metal by raising its fluidity and widening the freezing range and by decomposing the undesirable compounds already formed.

In view of the absorbing power of fused nickel for reducing gases, on the one hand, and for oxygen, on the other, the oxy-acetylene flame must be controlled with more than usual care, the most desirable being a slightly reducing flame with only a slight feather (approximately $\frac{1}{8}$in. long) beyond the tip of the luminous cone. A slightly higher degree of reduction will immediately become evident by increasing the porosity of the weld, whilst an oxidising, or even neutral, flame may cause excessive oxidation of the melt. Another important consideration in this connection is the size of the flame; that is to say, the proper size of the burner tip. If the flame is too small, melting of the nickel proceeds too slowly, the maximum heat range of the burner covers too small an area, and the fused metal solidifies too rapidly. In these circumstances the gases absorbed are not afforded sufficient time to escape, remaining in the metal and giving rise to porous welds. If, on the other hand, the burner tip is too large, the excessive heat will cause boiling of the weld metal, or even burning through at the seams. It is impossible here to give exact figures for the proper size of the welding flame, which is largely determined by the character of the weld and by the shape and size of the parts to be welded. A safe rule for the nickel welder is to employ a flame as large as is possible without causing boiling of the weld metal.

Welding rods or welding wire used for this purpose consist of nickel (or nickel alloys respectively) containing manganese, magnesium, aluminium, or other deoxidising agents, manganese being the addition usually preferred. Much, however, depends upon the percentage of the deoxidising agents added. In the case of manganese, 1/10 to 3/10 per cent. may be considered the safe range, the exact percentage depending upon the material welded and the amount of manganese contained in the basis material. Many of the nickel products sold in the form of sheets, tubes, &c., contain small percentages of manganese in order to improve their welding quality, and it is obvious that for material of this type the manganese content of the welding rods should be maintained proportionately low. The customary manganese content of nickel parts of welding quality ranges about 0·2 per cent. and for material of this type the welding rod should contain not more than about 0·1 per cent. of manganese. An excess of manganese is not desirable, although the disadvantages possibly

accruing from this source are not nearly as serious as a lack of deoxidising agent in the welding rod material.

Some authorities advise an addition of a small percentage of magnesium besides manganese in order to decompose possible sulphides in the weld. Experiments with alloys of this type have not always proved successful, although there appears to be no reason why this should be the case. It is true that manganese, if present in sufficiently large percentages, will also decompose nickel sulphide, forming manganese sulphide which enters the slag produced by the fluxing material. The amount required for this purpose, however, represents an undesirable excess, so that another reagent possessing a higher affinity for sulphur appears to be desirable. There is no doubt that the failures obtained with nickel-manganese rods containing magnesium are due to excessive magnesium content, which, after decomposing the traces of sulphur in the melt, leaves sufficient magnesium in the weld to produce undesirable alloying conditions. It should be expressly stated, for this reason, that such an excess is formed even by very small additions of magnesium to the welding rod material, if this is additional to the required manganese content. Where magnesium is added, this should be deducted from the manganese. For instance, where ordinarily the manganese content of a welding rod is found to be, say, 0·25 per cent. and an average sulphide content of, say, 0·01 per cent. in the weld metal requires the addition of 0·05 per cent. of magnesium, the welding rod metal should contain not more than perhaps 0·22 per cent. manganese and 0·05 per cent. magnesium. This point is not as unimportant as it may seem, in view of the small quantities involved, but since producers are not as a rule particularly careful in adding magnesium to special welding rod material containing manganese, the disappointing results sometimes obtained with these rods are easily explained.

The fluxes employed for nickel welding should be protective as well as curative in character, the latter property including a pronounced solvent action on the sulphides and oxides of nickel. Common borax, the universal flux, although frequently employed for this purpose, is not to be recommended. If present in sufficiently large quantities it improves the fluidity of the weld metal, but does not possess sufficient dissolving power for the injurious nickel compounds present to counteract the embrittling tendencies of the welding process. Besides increasing the fluidity of the melt to a maximum, nickel welding fluxes must therefore exhibit great deoxidising and solvent capacities. Borax is considerably improved by boric acid additions, whilst magnesium chloride or similar salts provide the deoxidising and solvent reaction required. Practically all special fluxes, such as the Inco, Rostosky, and other "patent mixtures," contain borax-boric acid deoxidant mixtures as basic constituents. They are non-corrosive to nickel or high-nickel alloys, and produce dense, clean welds. They are easily applied in either dry or paste form and easily removed after welding. The paste is usually made by mixing the powder with alcohol, but may also be prepared by dissolving the powder in the required amounts of boiling water. The author has found that the alcoholic mixture is the more easily applied and less troublesome form of the two. If the flux is used in its powder form, it should not be sprinkled over the welding surfaces, but applied with the welding rod, the heated end of the rod being dipped into dry flux.

It has been mentioned above that nickel exhibits a strong tendency to "work" under the influence of the welding flame, expanding and contracting to a higher degree than most other metals. This tendency, in connection with the pronounced hot-short range exhibited between the temperatures of 800 deg. and 1050 deg. Cent. (1450 deg. and 1850 deg. Fah.), necessitates special care in jigging the parts to be welded, the difficulties encountered from this source being more pronounced in sheet work than with heavy plates or castings. Whilst a certain amount of fastening or jigging is required to prevent warping of the sheets, contraction and expansion forces must be taken into account in order to prevent undue stresses in the weld and in the adjacent metal, which, like the weld itself, passes through the hot-short range. Wherever possible, the welded material should not, therefore, be clamped down too rigidly, or where this is necessary (as in the case of repairing nickel tanks, &c.), the clamps should be loosened from time to time in order to release the stresses set up by expansion or contraction.

Apart from the fact that rigid jigging is not the proper way of welding nickel, advanced nickel welding practice prevents too far a spread of the welding heat throughout the adjacent material, and this may well be combined with jigging arrangements. Instead of using clamps in ordinary sheet welding, heavy iron or steel bars tapering down to a narrow edge on one side, are placed on the sheets as near as possible to the welding seams. Whilst holding the sheets in place, they allow the metal to expand and contract in a natural manner, besides acting as chills which absorb the heat transmitted from the weld, thus counteracting the forces tending to cause buckling and warping of the sheets. Instead of iron or steel bars, copper bars are sometimes employed for this purpose in order still further to improve the chilling effect. However, since the base plates usually consist of heavy iron or steel sections, and also act as chills, it is obvious that the chilling effect acting on the comparatively thin nickel sheets from both sides does not necessitate the use of as highly conductive, but also comparatively expensive, a material as copper.

This method of "jigging" may be employed for butt welding as well as edge welding, the latter process being more satisfactory in welding thin nickel sheets. Attention is called to the fact that in edge welding the edges should not be flanged straight up, but to slightly less than 90 deg., so that only the upper edges touch each other. They should be as short as possible and of accurately equal height. No welding rods are required in this case, the edges being merely melted down, but special reducing fluxes must be used in order to replace the deoxidising materials ordinarily introduced with the welding rod metal. The alcoholic paste used for this purpose should be of higher consistency than ordinary nickel welding pastes, and must be painted on both sides of the two edges.

A frequent source of faulty nickel welding lies in incompletely fused seams. While perfectly dense and fused at the surface of the weld, the bottom edges may not have been thoroughly melted. The notch effect produced on bending the sheets at the weld then causes rapid fracture and opening of the seam. This may be due to the cooling effect of the base plate if the welding edges are in direct contact with the steel, the chilling effect thus produced also affecting the welding speed. Base plates should therefore be provided with grooves sufficiently deep and wide to form an insulating air cushion and to take up a small excess of weld metal, which, in

passing through the seam, will cause perfect fusion of the bottom edges.

Another factor of considerable importance is the direction of welding and the sequence of burner and welding rod. In welding from right to left, the oldest and most common method of nickel welding, the welding rod is carried ahead of the flame, which is moved to and fro along the edges of the sheets. Welding from left to right, which is now considered to be better suited to heavy sheets, &c., is carried out by conducting the flame ahead of the welding rod, moving the latter in a puddling motion, whilst the welding flame moves steadily forward. Right-to-left welding may, with some practice and skill, be employed for both thin and heavy sheets, whilst left-to-right welding should be applied only to heavy sheets, puddling with welding rod being less satisfactory for thin sheets than the to-and-fro motion of the flame, which delays solidification of the melt and assists the escape of the gases from the metal.

Wherever possible, the welding seam should be hammered in order to refine the grain and improve the strength and ductility of the weld. Although not quite as pronounced as in the case of copper welds, the increase in strength obtained by hammering usually amounts to 25–30 per cent., while in certain instances the increase may exceed 75 per cent. of the original strength of the weld metal.

### HAMMER-WELDING.

Nickel sheets may, like copper and aluminium parts, be welded by hammering. Indeed, hammer-welding of nickel sheets has, until recently, been preferred to autogenous welding, where the intricacies of the latter method have not been sufficiently understood, since it avoids the difficulties above outlined, the chief advantages of this process being the freedom from porosities and sulphide-oxide impurities frequently encountered in autogenous welds.

Although a very simple process in principle, much experience and skill is required to carry it out successfully, the most important factor being the correct heating of the welding surfaces. The best hammer-welding temperature is about 1000 deg. Cent. (1800 deg. Fah.), the useful temperature range being only about 100 deg. Fah. Since it is practically impossible to control the temperatures mechanically, long experience is required correctly to judge temperatures by feel (radiation) and appearance. If correct hammer-welding temperatures are not attained, the nickel welds incompletely or not at all, whilst temperatures above the narrow, useful range cause oxidation and burning of the nickel, resulting in weak welds.

Another important factor is the hot-shortness of nickel at the hammer-welding temperatures. This brittleness is not sufficiently pronounced to cause trouble if the overlapping edges of the sheets rest securely on the base plate, or anvil. The amount of overlapping depends on the type of weld produced and on the thickness of the sheets and ranges from 1½ to 2 times the thickness of the sheet. It is obvious that in the case of very thin nickel sheets the normal relation between the degree of overlapping and the thickness of sheet does not hold good, and that a minimum value of, say, ⅛in., must be maintained.

The tools required for hammer-welding nickel sheets consist of an anvil arranged to be heated to a constant temperature of 800 deg. Cent. (1450 deg. Fah.), which must be maintained during hammer-welding, an oxy-acetylene or oxy-hydrogen welding unit, and a welding hammer (a 1 lb. hammer with long handle).

Previous to hammer-welding the edges of the sheets must be scraped or brushed with a steel brush, and the perfectly bright surfaces freed from oily or fatty impurities with organic solvents. The cleaned surfaces must then be carefully guarded against dirt of any type, even oily finger prints exerting an undesirable influence on the process. Some hammer-welders claim to obtain best results by painting a thin paste of flux on the surfaces to be welded. Experience has shown, however, that this is entirely unnecessary if perfectly clean welding surfaces are maintained, and since the application of fluxes necessitates additional effort in order to remove the last traces from the weld, besides introducing additional sources of trouble where even slight traces of flux remain, most experienced hammer-welders refrain from this practice.

### NICKEL ALLOYS.

The most important nickel-rich alloys to be considered here are Monel metal and the various synthetic alloys resembling Monel metal in composition (Nicorros, Corronil, Silveroid, &c.), and, to a lesser degree, the copper-nickel alloys containing from 30 to 50 per cent. nickel.

There is not much difference between the welding of nickel-rich alloys and simple nickel. Since the former are more easily overheated, particular attention must be paid to the arrangement and handling of the flame. It is absolutely necessary to keep the weld metal quiet, since even a slight movement indicates excessive heat, the application of which invariably causes brittle and weak welds. Rods or strips of the same composition are used as filling material. Left-to-right welding is to be preferred. The same applies to the other copper-nickel alloys indicated above. Nickel silver alloys containing from 12 to 22 per cent. nickel, and from 18 to 25 per cent. zinc, react differently, their welding properties resembling those of brass.

## Letters to the Editor.

*(We do not hold ourselves responsible for the opinions of our correspondents.)*

### "'NEW' INDENTATION HARDNESS TESTS."

SIR,—The interesting article on "'New' Indentation Hardness Tests" in THE METALLURGIST for February 24th, mentions the well-known advantages which should accrue from a ball test using a constant angle of indentation. It concludes as follows:—

> "Unfortunately, no suggestion can be made as to a suitable mechanical device which would enable constant diameter impressions to be made. This problem must be left to some enterprising inventor who would probably find that his efforts were well rewarded.

In the "Carnegie Scholarship Memoirs" (Vol. XIX.) of the Iron and Steel Institute for 1930, I have fully described an experimental hardness testing machine which successfully gives results on metals according to the constant diameter principle. HUGH O'NEILL.

The Victoria University of Manchester,
February 27th.

[We are glad that Dr. O'Neill has drawn our attention to his apparatus which the writer of the review-abstract regrets he had overlooked. It seems just a little doubtful, however, whether the electrical contact method employed by Dr. O'Neill would be entirely satisfactory for workshop use.—ED. THE E.]